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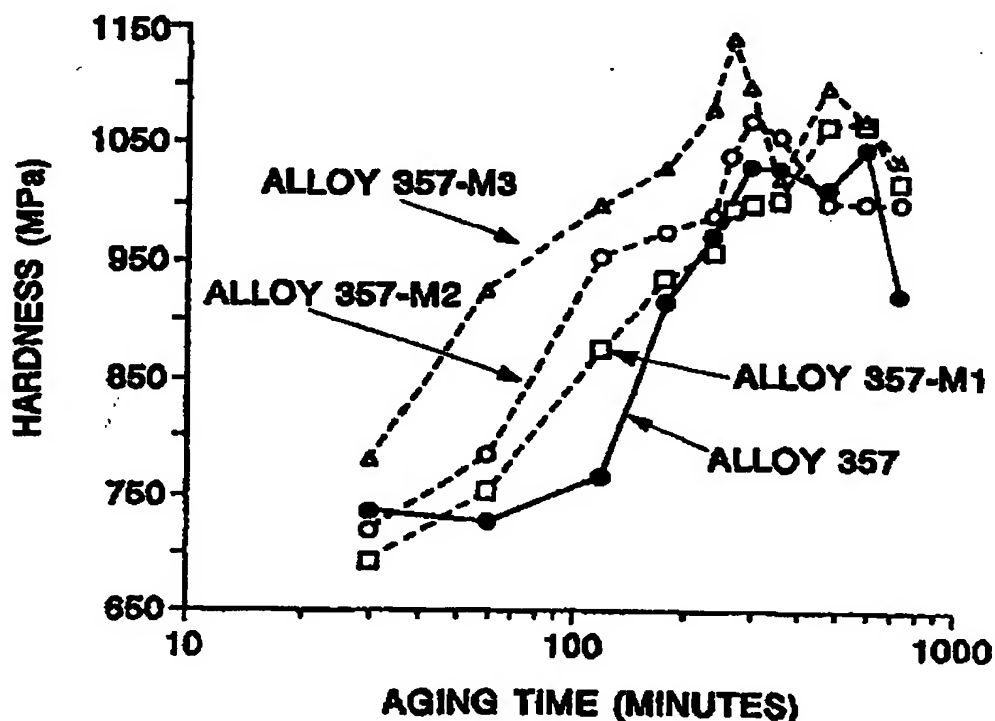
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(54) Title: HIGH STRENGTH ALUMINUM CASTING ALLOYS FOR STRUCTURAL APPLICATIONS

(57) Abstract

Aluminum-based casting alloys which possess enhanced properties. The alloys include 0.01-10.0 weight percent scandium in combination with other alloying elements such as, for example, zirconium, copper, magnesium, tin and silicon. When utilized to cast near net shape aluminum alloy parts, the alloys provide enhanced properties. In one application, a 0.02 % offset yield strength of greater than about 60 ksi has been achieved.



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# HIGH STRENGTH ALUMINUM CASTING ALLOYS FOR STRUCTURAL APPLICATIONS

5

## FIELD OF THE INVENTION

The present invention relates generally to aluminum casting alloys and, more specifically, to aluminum casting alloys that comprise scandium in combination with other alloying elements to produce alloys with desirable properties. It is anticipated that such a high strength casting alloy system will be advantageous for producing new cost saving net shape hardware components and for improving existing aluminum cast alloy applications.

15

## BACKGROUND OF THE INVENTION

Aluminum alloys, by virtue of their relatively low density, high strength and elastic modulus, fatigue resistance and ease of fabricability, are used in a wide range of structural applications. Historically, this has been especially evident in the manufacturing of aircraft, where the advantageous properties of aluminum alloys has allowed designers to balance the critical weight saving issues with the assurance of safe operation for several decades. With regard to ground transportation, it is apparent that structural weight savings are becoming more critical as fuel consumption and air pollution concerns come to the forefront of technological issues. Automotive manufacturers are currently using aluminum in unprecedented tonnages. This upward trend of aluminum usage is expected to continue for several years.

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The multitude of aluminum alloys can be divided into the categories of wrought and cast aluminum alloys. Wrought aluminum alloys refers to the plastic deformation or cold working of the initial cast billet into a final desired shape. Deformation can be accomplished by rolling, extruding, forging and drawing. Each step can be used singly or in combination with one another to produce end products such as plate, sheet, forgings, extruded shapes and wire.

On a microstructural level, the working of the original billet significantly improves the characteristics of the as-cast structure in terms of 1) the grain size and shape, 2) fragmentation and redistribution of microconstituent particles and 3) the healing of internal casting defects such as porosity and microcracks. When combining these benefits with optimum heat treating steps (e.g., solution heat treating, quenching, and aging) subsequent to processing, the properties of wrought product forms are far superior to the properties observed in the original cast billet. The simplicity of these shapes allows for the administration of a uniform cold work step prior to aging. In certain alloy systems, this serves to create high energy sites for heterogeneous nucleation of strengthening precipitates, thereby providing another increment of strengthening.

The aforementioned microstructural advantages of wrought products relative to the original casting typically result in improvements in strength, ductility, fracture

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toughness, fatigue strength and reproducibility of properties from different lots of material. Accordingly, it is the wrought product forms that dominate the usage in very critical load bearing components.

- 5        Among all alloying elements used to strengthen wrought aluminum alloys, scandium (Sc), despite its rare occurrence, has received significant attention.

U.S. Pat. No. 3,619,181 to Willey discloses the addition of Sc to a wide range of binary, ternary and  
10       multicomponent wrought alloy systems. It is claimed that wrought aluminum alloys can be strengthened with Sc additions. Several model alloy systems were fabricated with and without Sc additions and tested for strength and ductility. Additions of 0.2 to 0.4 weight percent Sc caused  
15       both tensile strength and yield strength to increase. The use of a cold working step with the Sc alloys caused further increases in strength.

Sawtell and Jensen reported enhanced strength and superplastic formability when adding Sc to the wrought Al-Mg system (see "Mechanical Properties and Microstructures  
20       of Al-Mg-Sc Alloys," Sawtell, R.R. and Jensen, C.L., Metallurgical Transactions, V. 21A, February, 1990, pp. 421-430). It was stated that the equilibrium precipitate phase  $Al_3Sc$  is the most potent strengthener known in the  
25       aluminum based alloy system on an equal atomic fraction basis.

U.S. Pat. No. 5,055,257 to Chakrabarti et al. documents the enhancement of superplastic forming by using

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the thermal stability of the Al<sub>3</sub>Sc precipitates. Improvement in total superplastic elongation was achieved in a wrought Al-Mg alloy. It was also noticed that the total time to achieve a certain strain level was two orders of magnitude greater than previously achieved with other superplastic alloys. Based on this information, it was emphasized that similar mechanistic improvements can be realized for other wrought aluminum alloys.

U.S. Pat. Appl. Serial No. 08/249,023 to Tack discloses the use of Sc in combination with several other dispersoid forming elements to enhance the weldability and weld strength of aluminum alloys in the 2XXX, 5XXX, 6XXX and 7XXX wrought alloy systems. The Sc additions were especially advantageous when added to both the base alloy and the filler alloy.

Although a significant amount of work has detailed the benefit of alloying Sc into wrought aluminum alloys to improve properties and processing characteristics, the development of Sc-containing aluminum cast alloys has been largely overlooked.

Cast aluminum alloys differ greatly from wrought aluminum alloys in terms of alloy design goals, microstructure, processing steps and strengthening mechanisms. Each of these criteria are contrasted in Table 1. Because most cast alloys are ultimately used in the geometry of the original mold (i.e., "near net shape"), many of the beneficial processing steps used to produce wrought aluminum are not practical for use in castings.

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Accordingly, the alloy compositions for cast alloys are usually far different from that of the wrought alloys.

TABLE 1

CATEGORY	WROUGHT ALUMINUM ALLOYS	CAST ALUMINUM ALLOYS
5 Alloy Design Goals	High Mechanical Properties, Improved Formability	Improved Castability and High Fluidity
Microstructure	Development of Low Angle and High Angle Grain Boundaries Via Plastic Deformation During Multi-Step Processing, Ultra Fine Strengthening Precipitates	Large, Hard Particles in a Soft Matrix, Coarse Interdendritic Eutectic Phases
10 Typical Processing Steps	1-Casting of Original Billet 2-Homogenization 3-Processing into Wrought Product Forms 4-Solution Heat Treatment 5-Quench 6-Cold Work (Primarily for 2XXX Alloys) 7-Aging	1-Casting into a Sand Mold, Permanent Mold, High Pressure Die Casting or Squeeze Casting 2-Solution Heat Treatment 3-Quench 4-Aging
Strengthening Mechanisms	Hall-Petch Strengthening, Solid Solution Effects, Precipitation Hardening	Solid Solution and Precipitation Hardening, Limited to Interdendritic Locations

It is perhaps instructive to compare alloy compositions and properties by using the Al-Si alloy system as an example for both cast and wrought product forms. The solid solubility of Si in Al is about 1.65 weight percent. A commonly used high performance aluminum casting alloy is Aluminum Association alloy 357 with a nominal composition of Al - 7.0 Si - 0.55 Mg and minor amounts of Ti, Mn, Fe,

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Be, and Cu. The relatively high amount of Si affords excellent casting characteristics that are paramount to producing complex shapes. Mechanical properties in the highest strength temper (ultimate tensile strength = 52  
5 ksi, yield strength = 43 ksi, elongation = 5%) are among the highest in the aluminum cast alloy system. The wrought aluminum alloy 6061-T913 (Al - 0.60 Si - 1.0 Mg - 0.28 Mn - 0.20 Cr), however, has far superior properties (ultimate  
10 tensile strength = 67 ksi, yield strength = 66 ksi, elongation = 10%). Even though the alloying content is much lower for 6061, the benefits of primary processing, development of low and high angle grain boundaries and use of cold work combined with aging result in drastically improved properties relative to the cast alloy system. It  
15 is clear that in many critical load bearing structures, it would be difficult to justify a casting alloy over a wrought alloy.

Despite the property disadvantages of casting alloys relative to wrought alloys, designers are constantly  
20 seeking methods to decrease fabrication cost. For example, an aircraft door may consist of several hundred components that are riveted and bolted together. While the performance is quite adequate, it would be highly desirable to decrease the cost of producing such a component by casting an alloy  
25 into a one piece near net shape. For a given production run, the one step casting process would offer significant cost savings over the parts and labor intensive approach that is currently used. Furthermore, it would clearly be

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advantageous if a new, innovative cast alloy composition could be used with properties that are far superior to those developed thus far.

5

## SUMMARY OF THE INVENTION

The present invention generally relates to aluminum casting alloys that contain scandium. More specifically, the excellent casting characteristics inherent for aluminum cast alloy compositions are superimposed with strength and ductility properties normally associated with those attainable only in wrought alloy systems.

In one aspect, the present invention is a composition of a casting alloy with a primary alloying addition of one or more of: Cu in the range of 0.01 to about 15 weight percent, Mg in the range of 0.01 to about 15 weight percent, Zn in the range of 0.01 to about 25 weight percent, Sn in the range of 0.01 to about 12 weight percent, and/or Li in the range of 0.01 to about 10 weight percent. In addition, the alloy includes Sc in the range of 0.01 to about 10.0 weight percent. In addition to scandium and the primary alloying elements, the composition could further include several combinations of Ni, Cu, and Fe to enhance elevated temperature performance, singly or in combination with one another in the range of 0.20 to about 10.0 weight percent, ancillary alloying additions such as Zn, Sn, Bi, Cd, Pb, singly or in combination with one another in the range of 0.10 to 5.0 weight percent, grain refining additions of Ti, Cr, Mn, TiB<sub>2</sub>, B, Be, Zr, Y, V, Hf,

singly or in combination with one another in the range of 0.01 to 2.0 weight percent, chemical modifiers such as Na and Sr, singly or in combination with one another in the range of 0.001 to about 0.10 weight percent and  
5 phase refiners such as P in the range of 0.01 to about 0.30 weight percent.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 (Hardness-vs-Aging Time, SHT @ 540°C for 8.0 hours and aging @ 175°C) illustrates hardness readings  
10 for several alloys at selected time intervals for aging at 175°C.

Fig. 2 (Hardness-vs-Aging Time, SHT @ 540°C for 8.0 hours, aging @ 150°C for 8.0 hours + aging @ 175°C)  
15 illustrates hardness readings for several alloys at selected time intervals for aging at 150°C for 8 hours and at 175°C during measurements.

Fig. 3 (Hardness-vs-Aging Time, SHT @ 540°C for 8.0 hours and aging @ 250°C) illustrates hardness readings  
20 for several alloys at selected time intervals for aging at 250°C.

#### DETAILED DESCRIPTION

The general principle of this invention is the  
25 disclosure of new types of casting alloys that contain all of the advantageous properties required of castings: e.g., excellent fluidity and castability, combined with the favorable mechanical properties usually associated only with wrought aluminium alloys. The new alloys uti-  
30 lize Sc additions in the range of 0.01 to 10 weight percent, more preferably 0.10 to 2.0 weight percent, and most preferably 0.10 to 0.50 weight percent. It should be noted that the 0.10 to 0.50 range is preferred for most castings as 0.50 is the solid solubility limited  
35 for Sc in aluminium. This

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range can be increased further when using faster cooling. Furthermore, the range can be extended to very high Sc levels to produce hard intermetallic phases that are beneficial for applications that require high wear  
5 resistance.

The end use applications for such an alloy are quite extensive and varied, and include electrical rotors, structural members, cylinder heads, pistons (for automotive engines, air conditioners, business machines, industrial  
10 equipment), aerospace housings, gears pumps, bearings, engine blocks, nodes for connecting tubular structures, wheels, aircraft fittings, flywheel castings, machine tool parts, gear blocks, general automotive castings, rolling mill bearings, marine structures, pressure tight  
15 applications, recreational equipment, connecting rods and numerous other applications.

Along with the aforementioned end use applications that have already been established with conventional castings, the new class of Sc containing alloys may  
20 stimulate the use of castings in new, innovative design scenarios that were not previously achievable with conventional casting alloys. Primarily, these new applications would include the casting of very complex shapes that would replace structural components that are  
25 typically riveted, bolted, adhesively bonded or welded together with several different wrought or cast product shapes. One example could be a bold initiative to cast an entire bulkhead structure in an aircraft in place of the

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complex machining of an isogrid type structure from thick plate sections. By achieving a new strength regime with aluminum casting alloys, designers may have an endless menu of options that can significantly reduce manufacturing cost of structures.

In one aspect, the present invention includes the additions of Sc in the range of 0.01 to about 10.0 weight percent to various cast aluminum alloy systems. Main alloying elements for such systems may include silicon, copper and magnesium. Other possible alloying additions can be added for a wide range of purposes, including Be for reducing oxidation loss, modifying intermetallics and improving strength, Bi for improving machinability, B for enhancing grain nucleation, Cd for improved machinability, Ca to modify eutectic phases, Cr for grain growth resistance and improved corrosion resistance, Fe for increased hot tearing resistance and elevated temperature strength, Pb for improved machinability, Mn for internal casting soundness, Hg for sacrificial anode materials, Ni for enhanced high temperature properties, P for refinement of primary phases, Ag for increased precipitation hardening, Na for modifying eutectic phases, Sr for modifying eutectic phases, Sn for influencing precipitation reaction, Ti for refining grain structure, Y for grain refining, and Zn for improving aging response.

In one embodiment, an alloy system in accordance with the principles of the present invention is a modification of the Aluminum Association's alloy system 2XX. This alloy

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system generally comprises about (1.5-15.0) Cu, (0.01 - 8.0) Mg, (0.1 - 1.0) Ag, and (0.01-10.0) Sc. The copper content preferably ranges from about 3.0 to about 6.0, and more preferably from about 4.0 to about 5.0, weight percent. The magnesium content preferably ranges from about 0.01 to about 2.0, and more preferably from about 0.01 to about 0.80, weight percent. Moreover, the silver content preferably ranges from about 0.1 to about 0.8, and more preferably from about 0.1 to about 0.6, weight percent. The scandium content preferably ranges from about 0.1 to about 2.0, and more preferably from about 0.1 to about 0.7, weight percent.

Other alloying elements may also be included. For example, the alloy may include up to about 1.0 Mn, up to about 5.0 Ni, up to about 7.0 Si, up to about 2.0 Fe, up to about 4.0 Zn and up to about 0.1 Sn. When present, manganese may be present in an amount of about 0.1-1.0, preferably about 0.1-0.6 and more preferably about 0.1-0.4, weight percent. In addition, nickel may be present in an amount of about 0.01-5.0, preferably 0.01-2.5 and more preferably 0.01-0.5, weight percent. When utilized, silicon may be present in an amount of about 0.1-7.0, preferably 0.1-2.0 and more preferably 0.1-0.3, weight percent. Iron may be present in an amount of about 0.1-2.0, preferably 0.1-1.0 and more preferably 0.1-0.6, weight percent. Also, zinc may be present in an amount of about 0.01-4.0, preferably 0.01-2.0 and more preferably 0.01-1.0, weight percent. The alloy may further include up to about 2.0,

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preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of one or more grain refiners (e.g., Ti, Zr, Cr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf). The alloy may further include chemical modifiers such as Na and Sr, singly or in  
5 combination with one another, in an amount up to about 0.10 weight percent, and phase refiners such as P in an amount up to about 0.30 weight percent.

Specific embodiments which utilize one or more of the above-described features include:

10

Al-4.5Cu-0.40Mg-0.40Mn-0.70Ag-0.35Sc-0.18Zr-0.25Ti

Al-4.5Cu-0.40Mg-0.40Mn-0.70Ag-0.35Sc-0.18Zr-0.25Ti-  
0.20Y

Al-4.5Cu-0.40Mg-0.70Ag-0.35Sc-0.18Zr-0.25Ti-0.20Y

15

In an variation on the 2XX alloy system, one embodiment of the present invention comprises about (1.5-15.0) Cu, (0.01 - 8.0) Mg, (0.50-4.0) Zn, and (0.01-10.0) Sc. Preferably, the copper, magnesium and scandium  
20 contents are as noted above for the previously-described embodiment. In addition, other elements (e.g., Mn, Ni, Si, Fe, Sn, etc.) may be included as noted above, including up to about 1.0 Ag. The zinc content more preferably ranges from about 0.5 to about 2.0, and most preferably from about  
25 0.5 to about 1.0, weight percent. A specific embodiment which utilize one or more of the above-described features includes:

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Al-4.3Cu-0.40Mg-0.40Mn-3.0Zn-0.35Sc-0.18Zr-0.25Ti

Another specific alloy of the present invention which is patterned from the 2XX alloy system, and which may have element ranges generally in accordance with the above-noted principles, includes:

Al-4.5Cu-0.40Mg-0.40Mn-0.35Sc-0.18Zr-0.25Ti-0.20Y

10 In another embodiment, an alloy system in accordance with the principles of the present invention is a modification of the Aluminum Association's alloy system 3XX. In this embodiment, the alloy system comprises about (3.0 - 25.0) Si, (0.01 - 10.0) Sc, and up to about 3.0 weight percent nickel. The silicon content preferably ranges from about 4.0 to about 18.0, and more preferably from about 6.0 to about 18.0, weight percent. When present, nickel is preferable in an amount of about 0.01-3.0, and more preferably about 0.01-0.5, weight percent. Moreover, 15 the scandium content preferably ranges from about 0.01 to about 0.7, and more preferably from about 0.01 to about 0.5, weight percent.

Other alloying elements may also be included. For example, the alloy may include up to about 4.0 Mg, up to about 1.0 Mn, up to about 6.0 Cu, up to about 3.0 Fe, up to about 0.6 Cr, up to about 6.0 Zn, and up to about 1.0 Sn. When present, iron may be in an amount of about 0.01-3.0, and preferably 0.01-1.0, weight percent. Copper may be 25

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present in an amount of about 0.01-6.0, preferably 0.01-3.0 and more preferably 0.1-2.0, weight percent. Moreover, to improve machinability of the alloy, tin may be present in an amount of about 0.01-1.0, and preferably 0.01-0.50, weight percent. In addition, the alloy may include zinc in the amount of about 0.01-6.0, preferably 0.01-3.0, weight percent. When utilized, magnesium may be in an amount of about 0.01-4.0, preferably 0.01-2.0 and more preferably 0.01-0.7, weight percent. Manganese may be used in an amount of about 0.01-1.0, preferably 0.01-0.7 and more preferably 0.01-0.5, weight percent. In addition, chromium may be present in an amount of about 0.01-0.6, preferably 0.01-0.3, weight percent. The alloy may also include about up to about 2.0, preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of one or more grain refiners (e.g., Ti, Zr, Cr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf). The alloy may further include chemical modifiers such as Na and Sr, singly or in combination with one another, in an amount up to about 0.10 weight percent, and phase refiners such as P in an amount up to about 0.30 weight percent.

Specific alloys of this embodiment which comprise a hypoeutectic amount of silicon and which utilize one or more of the above-described features include:

Al-7.0Si-0.6Mg-0.35Sc-0.18Zr-0.2Ti

Al-7.0Si-0.6Mg-0.35Sc-0.18Zr-0.2Ti-0.2Y

Al-7.0Si-1.0Mg-0.35Sc-0.18Zr-0.2Ti

Al-7.0Si-0.6Mg-0.35Sc-0.18Zr-0.25Cu-0.35Zn-0.2Ti

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Specific alloys having eutectic or hypereutectic amounts of silicon and which utilize one or more of the above-described features include:

5        Al-17.0Si-1.3Fe-1.0Mg-5.0Cu-2.5Ni-0.35Sc-0.18Zr-0.2Ti  
         Al-17.0Si-0.5Fe-1.0Mg-5.0Cu-0.35Sc-0.18Zr-0.2Ti  
         Al-17.0Si-1.5Fe-1.0Mg-0.6Cu-0.5Ni-0.5Zn-0.30Sn-0.35Sc-  
         0.18Zr-0.20Ti

         Al-17.0Si-1.3Fe-1.0Mg-5.0Cu-2.5Ni-0.35Sc-0.18Zr-  
10      0.20Ti-0.20Y

         Al-12.0Si-1.3Fe-0.6Mg-3.5Cu-0.40Mn-0.50Ni-3.0Zn-  
         0.35Sn-0.35Sc-0.18Zr-0.20Ti

         Al-12.0Si-1.3Fe-1.0Mg-1.0Cu-2.5Ni-0.35Zn-0.35Sc-  
         0.18Zr-0.20Ti

15

         In a variation on the 3XX alloy system, one embodiment of the present invention comprises about (3.0 - 25.0) Si, (0.01-2.0)Zr, and (0.01 - 10.0) Sc. Preferably, the silicon, and scandium contents are as noted above for the  
20      previously-described embodiment. The zirconium content preferably comprises 0.01-1.0, and more preferably 0.01-0.5, weight percent. Other alloying elements may also be included, as noted above.

         In another embodiment, an alloy system in accordance  
25      with the principles of the present invention is a modification of the Aluminum Association's alloy system 4XX. In this embodiment, the alloy system comprises about (3.0 - 25.0) Si, (0.01-10.0) Sc and up to about 1.0 Cu.

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Preferably, silicon is present in an amount of about 4.0-15.0, and more preferably 4.5-13, weight percent. When present, copper is preferably in an amount of about 0.01-1.0, and more preferably 0.1-1.0, weight percent.

5 Moreover, the scandium content preferably ranges from about 0.01 to about 0.7, and more preferably from about 0.01 to about 0.5, weight percent.

Other alloying elements may also be included. For example, the alloy may include up to about 0.1 Mg, up to

10 about 3.0 Fe, up to about 0.5 Mn, up to about 0.5 Cr, up to about 1.0 Zn, up to about 0.2 Sn, and up to about 1.0 Ni. When present, iron is preferably in the amount of about 0.01-3.0, and more preferably 0.2-2.0, weight percent. In addition, when used, the other alloying elements are

15 preferably in the following amounts: about 0.01-0.1 Mg, about 0.01-0.5 Mn, about 0.01 - 0.50 Cr, about 0.01 - 1.0 Zn, about 0.01 - 0.20 Sn and about 0.01-1.0 Ni. Moreover, the alloy may include up to about 2.0, preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of

20 one or more grain refiners (e.g., Ti, Zr, Cr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf). The alloy may further include chemical modifiers such as Na and Sr, singly or in combination with one another, in an amount up to about 0.10 weight percent, and phase refiners such as P in the amount up to about 0.30

25 weight percent.

Specific alloys of this embodiment which utilize one or more of the above-described features include:

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Al-12.0Si-2.0Fe-1.0Cu-0.35Mn-0.50Ni-0.50Zn-0.35Sc-  
0.18Zr

Al-12.0Si-2.0Fe-1.0Cu-0.35Mn-0.50Ni-0.50Zn-0.35Sc-  
0.18Zr-0.20Y

5 Al-6.0Si-0.6Fe-0.25Cu-0.35Mn-0.50Zn-0.35Sc-0.18Zr

Al-6.0Si-0.6Fe-0.25Cu-0.35Mn-0.50Zn-0.35Sc-0.18Zr-  
0.20Y

In a variation on the 4XX alloy system, one embodiment  
10 of the present invention comprises about (3.0 - 25.0) Si,  
(0.01 - 10.0) Sc, and up to about 3.0 Ni. Preferably, the  
silicon and scandium contents are as noted above for the  
previously-described embodiment. The nickel content is  
preferably less than 2.0, and more preferably less than  
15 1.0, weight percent. Other alloying elements may also be  
included, as noted above.

In another embodiment, an alloy system in accordance  
with the principles of the present invention is a  
modification of the Aluminum Association's alloy system  
20 5XX. In this embodiment, the alloy system generally  
comprises about (6.0 - 12.0) Mg and (0.01 - 10.0) Sc. The  
magnesium content is preferably from about 7.0 to about  
10.0. Moreover, the scandium content preferably ranges  
from about 0.01 to about 0.7, and more preferably from  
25 about 0.01 to about 0.5, weight percent.

The alloy may further include up to about 1.0 Si, up  
to about 2.0 Fe, up to about 0.5 Cu, up to about 1.0 Mn, up  
to about 0.5 Cr, up to about 0.2 Ni, up to about 0.5 Zn,

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and up to about 02. Sn. When used, silicon may be in the amount of about 0.01-1.0 and tin may be in the amount of about 0.01-0.2. Iron may be present in the amount of about 0.01-2.0, preferably 0.01-1.3, weight percent. When present, copper is preferably in the amount of about 0.1-0.5, more preferably 0.1-0.3, weight percent. When manganese is used, the content is preferably 0.01-1.0, and more preferably 0.01-0.6, weight percent. Other weight percentages of elements may include: 0.01-0.5, preferably 0.01-0.25, chromium; 0.01-0.2, preferably 0.01-0.15, nickel; and 0.01-0.5, preferably 0.01-0.35, zinc. Moreover, the alloy may include up to about 2.0, preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of one or more grain refiners (e.g., Ti, Zr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf). The alloy may further include chemical modifiers such as Na and Sr, singly or in combination with one another, in the amount up to about 0.10 weight percent and phase refiners such as P in the amount up to about 0.30 weight percent.

Specific alloys of this embodiment which utilize one or more of the above-identified features include:

Al-10.0Mg-0.35Sc-0.18Zr-0.2Ti

Al-7.0Mg-0.35Sc-0.2Mn-0.18Zr-0.2Ti

Other specific alloys of the present invention which are patterned from the 5XX alloy system, and which may have

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element ranges generally in accordance with the above-noted principles, include:

Al-4.0Mg-0.4Mn-0.35Sc-0.18Zr-0.20Ti

5

Al-4.0Mg-1.8Si-0.4Mn-0.35Sc-0.18Zr-0.2Ti

In a variation on the 5XX alloy system, one embodiment of the present invention comprises about (3.0-11.0) Mg, (0.01-2.0) Zr, and (0.01-10.0) Sc. The scandium content is preferably as noted above for the previously-described embodiment. The magnesium content is preferably about 3.5-10.5 weight percent, and the zirconium content is preferably about 0.01-1.0, more preferably 0.01-0.5, weight percent. Other alloying elements may also be included, as noted above.

15

Specific alloys of this embodiment which utilized one or more of the above-described features include:

Al-4.0Mg-0.4Mn-0.35Sc-0.18Zr-0.2Ti

20

Al-4.0Mg-1.8Si-0.4Mn-0.35Sc-0.18Zr-0.2Ti

In another embodiment, an alloy system in accordance with the principles of the present invention is a modification of the Aluminum Association's alloy system 7XX. In this embodiment, the alloy generally comprises about (2.0 - 12.0) Zn, (0.01 - 3.0) Mg, (0.01 - 10.0) Sc, and is substantially free of chromium. Preferably, zinc is present in an amount of about 3.0-9.0, and more preferably

25

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6.0-8.0, weight percent. Magnesium may preferably be in an amount of about 0.01-2.5, and more preferably 0.01-2.0, weight percent. Moreover, the scandium content preferably ranges from about 0.01 to about 0.7, and more preferably  
5 from about 0.01 to about 0.5, weight percent.

Other alloying elements may also be included. For example, the alloy may include up to about 0.3 Si, up to about 0.8 Fe, up to about 0.6 Cu, up to about 0.3 Mn, up to about 0.1 Ni, and up to about 0.1 Sn. When present, iron  
10 may be in the amount of about 0.01-2.0, preferably 0.01-1.5 and more preferably 0.01-0.8, weight percent. Silicon may be present in an amount of about 0.01-0.50, and preferably 0.01-0.30, weight percent. When used, copper may be in the amount of about 0.01-2.0, preferably 0.01-1.0 and more  
15 preferably 0.01-0.6, weight percent. Tin and nickel may each be present in an amount of about 0.01-0.20, and preferably 0.01-0.10, weight percent. In addition, manganese may be in the amount of about 0.01-1.0, preferably 0.01-0.6 and more preferably 0.01-0.3, weight  
20 percent. Moreover, the alloy may include up to about 2.0, preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of one or more grain refiners (e.g., Ti, Zr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf). The alloy may further include chemical modifiers such as Na and Sr, singly or in  
25 combination with one another, in the amount up to about 0.10 weight percent and phase refiners such as P in the amount up to about 0.30 weight percent.

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Specific alloys of this embodiment which utilize one or more of the above-described features include:

Al-7.0Zn-1.5Mg-0.35Sc-0.18Zr-0.2Ti

5 Al-7.0Zn-1.5Mg-0.35Sc-0.18Zr-0.20Ti-0.2Y

In another embodiment, an alloy system in accordance with the principles of the present invention is a modification of the Aluminum Association's alloy system  
10 8XX. In this embodiment, the alloy generally comprises about (2.0-10.0) Sn and (0.01 - 10.0) Sc. Preferably, tin is present in an amount of about 4.0-8.0, and more preferably 5.5-7.0, weight percent. Moreover, the scandium content preferably ranges from about 0.01 to about 0.7, and  
15 even more preferably from about 0.01 to about 0.5, weight percent.

Other alloying elements may also be included. For example, the alloy may include up to about 10.0 Si, up to about 1.0 Fe, up to about 5.0 Cu, up to about 0.5 Mn, up to  
20 about 2.0 Ni, and up to about 1.0 Mg. When used, iron can be in the amount of about 0.01-1.0, preferably 0.01-0.7, weight percent. In addition, silicon may be present in an amount of about 0.01-10.0, preferably 0.40-7.0 and more preferably 0.7-7.0, weight percent. When present, copper  
25 may be in the amount of about 0.01-5.0, preferably 0.70-4.0, weight percent. Nickel may also be present in an amount of about 0.01-2.0, preferably 0.01-1.5, weight percent. The alloy may further include (0.01-0.50) Mn and

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(0.01-1.0)Mg. Moreover, the alloy may include up to about 2.0, preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of one or more grain refiners (e.g., Ti, Zr, Cr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf). The alloy  
5 may further include chemical modifiers such as Na and Sr, singly or in combination with one another, in the amount up to about 0.10 weight percent, and phase refiners such as P in the amount up to about 0.30 weight percent.

In another embodiment, an alloy system in accordance  
10 with the principles of the present invention is an alloy system that is based upon the Al-Li alloy system for which there is currently no general Aluminum Association designation. The alloy system of the present invention generally comprises about (0.02 - 4.0) Li and (0.01-  
15 10.0) Sc. The Lithium content is preferably about 0.2-3.0, and more preferably 0.4-2.0, weight percent. The scandium content is preferably about 0.1-0.7, and more preferably 0.1-0.5, weight percent.

In addition, the alloy may include up to about 6.0 Cu,  
20 up to about 1.0 Fe, up to about 0.5 Mn, up to about 2.0 Ni, up to about 6.0 Mg, up to about 2.0 Sn, and up to about 1.0 Ag. When such alloying elements are used, they may preferably be in the following weight percentages: (0.01-6.0), preferably (2.0-6.0) and more preferably (2.0-5.0)  
25 Cu; (0.01-1.0), preferably (0.01-0.5) and more preferably (0.01-0.2) Fe; (0.01-0.5), preferably (0.01-0.3) Mn; (0.01-2.0), preferably (0.01-1.0) and more preferably (0.01-0.5) Ni; (0.01-6.0), preferably (0.01-5.0) Mg; (0.01-0.2) Sn;

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(0.01-1.0), preferably (0.01-0.8) Ag. Moreover, the alloy may include up to about 2.0, preferably 0.01-1.0 and more preferably 0.01-0.7, combined weight percent of one or more grain refiners (e.g., Ti, Zr, Mn, V, B, TiB<sub>2</sub>, Be, Y and Hf).  
5 The alloy may further include chemical modifiers such as Na and Sr, singly or in combination with one another, in the amount up to about 0.10 weight percent and phase refiners such as P in the amount up to about 0.30 weight percent.

Specific alloys of this embodiment which utilize one  
10 or more of the above-described features include:

Al-1.0Li-4.5Cu-0.80Ag-0.60Mg-0.35Sc-0.18Zr-0.20Ti

Al-0.60Li-4.5Cu-0.80Ag-0.60Mg-0.35Sc-0.18Zr-0.20Ti

Al-0.60Li-4.5Cu-0.80Ag-0.60Mg-0.35Sc-0.18Zr-0.20Ti-0.20Y

15 Al-2.0Li-3.0Cu-0.80Ag-0.60Mg-0.35Sc-0.18Zr-0.20Ti

Al-2.0Li-3.0Cu-0.80Ag-0.60Mg-0.35Sc-0.18Zr-0.20Ti-0.20Y

Al-2.0Li-5.0Mg-0.35Sc-0.18Zr-0.20Ti

Al-1.8Li-6.0Mg-0.35Sc-0.18Zr-0.20Ti-0.20Y

20 In another aspect, the new casting alloy will be cast using the conventional method of pouring the molten alloy mixture into a permanent, sand or investment type mold or alternatively cast using advanced techniques such as high pressure die casting or squeeze casting to produce a near  
25 net shape cast part. The near net shape part can then be heat treated in accordance with the practice that involves the steps of solution heat treatment at temperatures approaching the solidus temperature of a given alloy,

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quenching into water, and aging at temperatures ranging from ambient to about 400°C. Alternatively, a two-step aging process can be utilized. Such a two-step process may include primary aging at a low temperature (e.g., less than about 190°C, preferably about 160°C) for an extended period of time (e.g., longer than about 12 hours, preferably about 24 hours) followed by secondary aging at a high temperature (e.g., greater than about 190°C, preferably about 220°C) for a short period of time (e.g., not long enough to fully anneal the alloy, preferably about 2 hours). Additional processing steps such as hot isostatic pressing, machining, surface modification and shot peening can be applied to further improve the casting alloys disclosed in this invention.

By utilizing the alloys of the present invention to form near net shape cast parts, significantly improved cast alloy properties can be achieved. For example, alloys which embody the present invention have been shown to have yield strengths (0.2% offset in the cast condition) in excess of 60 ksi, as shown in the following examples.

#### EXAMPLE 1

Four alloys of the compositions listed in Table 2 were cast into a permanent mold. The alloys consisted of a 357 type cast aluminum alloy with no Sc additions and three additional 357 type alloys with Sc levels of 0.08 (357-M1), 0.19 (357-M2), and 0.31 (357-M3) weight percent. Each of the four castings was solution heat treated at 540°C for

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8.0 hours, immediately quenched into ambient temperature water upon removal from the furnace and allowed to stabilize for several days. Aging curves were generated for the four alloys by taking Vickers hardness measurements in accordance with the American Society for Testing and Materials (ASTM) standard E92-82 at selected time intervals for a wide range of temperatures, as illustrated in Fig. 1.

TABLE 2

Alloy Number	Chemical Composition (Weight Percent)					
	Al	Si	Mg	Fe	Ti	Sc
357	*	5.64	0.63	0.11	0.12	0
357-M1	*	5.58	0.53	0.12	0.12	0.08
357-M2	*	6.50	0.41	0.11	0.12	0.19
357-M3	*	6.15	0.40	0.13	0.12	0.31

As shown in Figure 1, each of the three Sc containing alloys displays higher hardness readings over a wide range of aging times at a temperature of 175°C. This is especially surprising given that the 357 alloy is by far the highest strength alloy in the Al-Si-Mg cast alloy system. Moreover, the Mg content is higher in the 357 alloy (0.63%) than in the 357-M1 (Mg=0.53%), 357-M2 (Mg=0.41) and 357-M3 (Mg=.40%) alloys. Since published yield strength values (source: Metals Handbook Desk Edition, American Society for metals, H.E. Boyer and T.L. Gall, eds., 1985, pp. 6.48 - 6.62) for 357-T6 (0.55% Mg,

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yield strength = 43 ksi) are about 43% greater than those obtained with alloy 356-T6 (same composition as the 357 with 0.35% Mg, yield strength = 30ksi), it would be expected that the hardness of the 357 variant in this study  
5 would be far greater than the hardness values attained for the 357-M1, 357-M2 and 357-M3 variants. Clearly, the Sc additions are very potent in overcoming this large property disparity that is observed with slightly different Mg levels. If the Mg content were adjusted to the 0.60 weight  
10 percent level or above, it is likely that the hardness response would be even greater.

In a variation on the above-noted aging treatment, a two step aging treatment consisting of an initial step of 150°C for 8.0 hours followed by aging at 175°C at selected  
15 time intervals was applied to the four alloys (Figure 2). As aging time progresses, the Sc containing alloys attain hardness levels that exceed the hardness levels of 357, e.g. after 18 hours at 175°C, alloy 357-M2 has a 13% greater hardness reading than alloy 357. It is evident  
20 that a two step aging treatment may further widen the gap between Sc containing castings and non-Sc containing castings.

In another test, to evaluate the hardness of the four alloys after exposure to an elevated temperature, hardness  
25 readings were taken after various exposure times at 250°C. As illustrated in Figure 3, the hardness of the three Sc containing alloys is far greater than alloy 357 after 20 hours of exposure. One unusual aspect of this hardness

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curve is that alloy 357-M1 has a somewhat negligible 3.0% hardness advantage over 357 after 6.0 hours of exposure, and after 20 hours of exposure, the advantage grows to 25%. This is an indication that applications which require good strength at elevated temperatures, e.g. cast engine components and structures, would benefit from additions of Sc.

## EXAMPLE 2

10 To assess the strength and ductility of the four alloys, three point bend testing was conducted in accordance with ASTM test procedure E855, "Bend Testing of Metallic Flat Materials for Spring Applications Involving Static Loading".

15 The proof strength can be calculated by determining a load level at the point in which a permanent deformation ( $\delta_p$ ) of 0.01% occurs. This permanent deflection at the center of the span is:

$$\delta_p = 0.0001 L^2/6h$$

20 where  $\delta_p$  is the permanent deflection, L is the span length between supports and h is the specimen thickness. The bending strength ( $\sigma_p$ ) can then be determined by the equation:

$$\sigma_p = 1.5 P_p L/bh^3$$

25 where  $P_p$  = the load which produces permanent deformation, L = the span length between supports, b = the specimen width and h = the specimen thickness.

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As a typical tension test, an offset tangent line can be drawn to the elastic portion of the load-deflection curve for a given strain level. Accordingly, the important parameters measured among the four alloys are bending proof stress ( $\sigma_p$ ), bending strength at a 0.20% offset strain level ( $\sigma_{0.2}$ ), bending strength at a 2.0% offset strain level ( $\sigma_{2.0}$ ) and strain to failure of the outermost layer of the specimen ( $\epsilon_f$ ).

A set of three bend test specimens for each of the four alloys was used to assess bending strength and ductility for the four cast alloys after equivalent heat treatment processing that included solution heat treatment at 540°C for 8.0 hours, water quenching and aging at 170°C for 60 hours (T6 heat treatment). The mean values taken from the three bend tests for each alloy shown in Table 3 indicate that a significant strength advantage is demonstrated for the alloys containing Sc despite the lower Mg levels of these alloys. Again, a Mg difference of 0.20 weight percent can result in a 43% yield strength difference. In contrast, it is surprising that alloy 357-M3 has a 33% strength advantage (on the basis of the  $\sigma_{2.0}$  value) over alloy 357 despite having less Mg than alloy 357. If the Sc was not present in the alloy, a 43% strength disadvantage would be expected. This underlines the strength potential for alloys with sufficient levels of both Mg and Sc present.

TABLE 3

Alloy Number	Bending Strength Values, ksi			Strain or Failure, $\epsilon_f$
	$\sigma_p$	$\sigma_{0.2}$	$\sigma_{2.0}$	
357	43.9	53.0	65.1	4.94
357-M1	49.2	61.1	74.7	2.98
357-M2	52.4	65.2	78.5	3.81
357-M3	54.2	68.0	86.6	3.25

In another test, a two step aging treatment was applied to the four alloys that included a first step at 150°C for 8.0 hours followed by 175°C for 6.0 hours. Three specimens from each alloy were then subjected to the bend test, with the mean values listed in Table 4. As with the one step aging process, the strength values were again improved for the novel alloys 357-M1, 357-M2, and 357-M3. One surprising aspect, however, was observed with the two step aging process. In addition to the enhanced strength, ductility was also improved relative to the 357 alloy. For example, alloy 357-M2 has a 10% larger value of  $\sigma_{2.0}$  relative to 357 with a simultaneous 100% improvement in ductility. Since strength and ductility are usually inversely proportional, it is unusual that both properties can be improved. As mentioned previously, this is even more significant since alloys 357-M1, 357-M2 and 357-M3 are handicapped with critically lower Mg levels.

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TABLE 4

Alloy Number	Bending Strength Values, ksi			Strain or Failure, $\epsilon_f$
	$\sigma_p$	$\sigma_{0.2}$	$\sigma_{2.0}$	
357	46.9	55.7	67.9	5.06
357-M1	48.0	57.2	71.6	5.67
357-M2	48.5	60.5	74.5	10.1
357-M3	49.1	60.9	77.7	3.25

Given the data presented in this disclosure, it is  
evident that the advantages of the casting process in terms  
of obtaining near net shapes can be combined with new types  
of unique casting alloy compositions employing Sc  
additions. The proportion of strength and ductility  
increases attainable would make certain cast alloys  
competitive with wrought aluminum alloys, an occurrence  
that has not been achieved in the aluminum alloy system.

Thus, in another aspect of the present invention, a  
method for forming a near net shape cast part is provided.  
The method includes the steps of selecting aluminum-based  
alloy having from about 0.01 to about 10.0 weight percent  
scandium, heating the alloy to above its melting point,  
pouring the molten alloy into a mold, cooling the alloy to  
below its melting point, and achieving a near net shape  
cast part having a 0.02% offset yield strength of greater  
than about 60 ksi. Preferably, the selected alloy is one  
of the alloys described above.

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The foregoing description of the present invention has been presented for purposes of illustration and description. Furthermore, the description is not intended to limit the invention to the form disclosed herein.

5 Consequently, variations and modifications commensurate with the above teachings, and skill and knowledge of the relevant art, are within the scope of the present invention. The embodiments described hereinabove are further intended to explain best modes known of practicing

10 the invention and to enable others skilled in the art to utilize the invention in such, or other embodiments and with various modifications required by the particular application(s) or use(s) of the present invention. It is intended that the appended claims be construed to include

15 alternative embodiments to the extent permitted by the prior art.

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What is claimed is:

1. An aluminum-based casting alloy comprising:  
from about 1.5 to about 15.0 weight percent  
copper;  
5 from about 0.01 to about 8.0 weight percent  
magnesium;  
from about 0.1 to about 1.0 weight percent  
silver;  
from about 0.01 to about 10.0 weight percent  
10 scandium; and  
from about 60 to about 99 weight percent  
aluminum.
2. An aluminum-based casting alloy, as claimed in  
claim 1, wherein said alloy comprises from about 0.1 to  
15 about 0.7 weight percent scandium.
3. An aluminum-based casting alloy, as claimed in  
claim 2, wherein said alloy comprises from about 0.1 to  
about 0.5 weight percent scandium.
4. An aluminum-based casting alloy, as claimed in  
20 claim 1, consisting essentially of:  
from about 1.5 to about 15.0 weight percent  
copper;  
from about 0.01 to about 8.0 weight percent  
magnesium;  
25 from about 0.1 to about 1.0 weight percent  
silver;  
from about 0.01 to about 10.0 weight percent  
scandium;

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up to about 1.0 weight percent manganese;  
up to about 5.0 weight percent nickel;  
up to about 7.0 weight percent silicon;  
up to about 2.0 weight percent iron;  
5 up to about 4.0 weight percent zinc;  
up to about 0.1 weight percent tin;  
up to about 2.0 weight percent grain refiners;  
up to about 0.1 weight percent chemical  
modifiers;  
10 up to about 0.3 weight percent phase refiners;  
and  
the remainder consisting essentially of aluminum  
and incidental impurities.

5. An aluminum-based casting alloy, as claimed in  
15 claim 1, consisting essentially of:  
about 4.5 weight percent copper;  
about 0.4 weight percent magnesium;  
about 0.7 weight percent silver;  
about 0.4 weight percent manganese;  
20 about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and  
the remainder consisting essentially of aluminum  
and incidental impurities.

25 6. An aluminum-based casting alloy, as claimed in  
claim 1, consisting essentially of:  
about 4.5 weight percent copper;  
about 0.4 weight percent magnesium;

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about 0.7 weight percent silver;  
about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and

5           the remainder consisting essentially of aluminum  
and incidental impurities.

7.   An aluminum-based casting alloy comprising:  
from about 1.5 to about 15.0 weight percent  
copper;  
10           from about 0.01 to about 8.0 weight percent  
magnesium;  
from about 0.5 to about 4.0 weight percent zinc;  
from about 0.01 to about 10.0 weight percent  
scandium; and  
15           from about 60 to about 98 weight percent  
aluminum.

8.   An aluminum-based casting alloy, as claimed in  
claim 7, wherein said alloy comprises from about 0.1 to  
about 0.7 weight percent scandium.

- 20       9.   An aluminum-based casting alloy, as claimed in  
claim 8, wherein said alloy comprises from about 0.1 to  
about 0.5 weight percent scandium.

10.   An aluminum-based casting alloy, as claimed in  
claim 7, consisting essentially of:  
25           from about 1.5 to about 15.0 weight percent  
copper;  
from about 0.01 to about 8.0 weight percent  
magnesium;

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from about 0.5 to about 4.0 weight percent zinc;  
from about 0.01 to about 10.0 weight percent  
scandium;

5 up to about 1.0 weight percent manganese;  
up to about 5.0 weight percent nickel;  
up to about 7.0 weight percent silicon;  
up to about 2.0 weight percent iron;  
up to about 1.0 weight percent silver;  
up to about 0.1 weight percent tin;  
10 up to about 2.0 weight percent grain refiners;  
up to about 0.1 weight percent chemical  
modifiers;  
up to about 0.3 weight percent phase refiners;  
and  
15 the remainder consisting essentially of aluminum  
and incidental impurities.

11. An aluminum-based casting alloy, as claimed in  
claim 7, consisting essentially of:

20 about 4.3 weight percent copper;  
about 0.4 weight percent magnesium;  
about 3.0 weight percent zinc;  
about 0.4 weight percent manganese;  
about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
25 refiners; and  
the remainder consisting essentially of aluminum  
and incidental impurities.

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12. An aluminum-based casting alloy comprising:  
about 4.5 weight percent copper;  
about 0.4 weight percent magnesium;  
about 0.4 weight percent manganese;  
5 about 0.35 weight percent scandium  
about 0.18 weight percent zirconium;  
about 0.25 weight percent titanium;  
about 0.2 weight percent yttrium; and  
from about 60 to about 99 weight percent  
10 aluminum.
13. An aluminum-based casting alloy comprising:  
from about 3.0 to about 25.0 weight percent  
silicon;  
from about 0.01 to about 10.0 weight percent  
15 scandium;  
up to about 3.0 weight percent nickel; and  
from about 60 to about 97 weight percent  
aluminum.
14. An aluminum-based casting alloy, as claimed in  
20 claim 13, wherein said alloy comprises from about 0.1 to  
about 0.7 weight percent scandium.
15. An aluminum-based casting alloy, as claimed in  
claim 14, wherein said alloy comprises from about 0.1 to  
about 0.5 weight percent scandium.
- 25 16. An aluminum-based casting alloy, as claimed in  
claim 13, consisting essentially of:  
from about 3.0 to about 25.0 weight percent  
silicon;

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from about 0.01 to about 10.0 weight percent  
scandium;

5 up to about 3.0 weight percent nickel;  
up to about 4.0 weight percent magnesium;  
up to about 1.0 weight percent manganese;  
up to about 6.0 weight percent copper;  
up to about 3.0 weight percent iron;  
up to about 0.6 weight percent chromium;  
up to about 6.0 weight percent zinc;  
10 up to about 1.0 weight percent tin;  
up to about 2.0 weight percent grain refiners;  
up to about 0.1 weight percent chemical  
modifiers;  
up to about 0.3 weight percent phase refiners;

15 and

the remainder consisting essentially of aluminum  
and incidental impurities.

17. An aluminum-based casting alloy, as claimed in  
claim 13, consisting essentially of:

20 about 7.0 weight percent silicon;  
about 0.6 weight percent magnesium;  
about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and

25 the remainder consisting essentially of aluminum  
and incidental impurities.

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18. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

about 7.0 weight percent silicon;  
about 1.0 weight percent magnesium;  
5 about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain refiners; and

the remainder consisting essentially of aluminum and incidental impurities.

10 19. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

about 7.0 weight percent silicon;  
about 0.6 weight percent magnesium;  
about 0.25 weight percent copper;  
15 about 0.35 weight percent zinc;  
about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain refiners; and

the remainder consisting essentially of aluminum  
20 and incidental impurities.

20. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

about 17.0 weight percent silicon;  
about 1.0 weight percent magnesium;  
25 about 1.3 weight percent iron;  
about 5.0 weight percent copper;  
about 2.5 weight percent nickel;  
about 0.35 weight percent scandium;

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about 0.01 to about 1.0 weight percent grain refiners; and

the remainder consisting essentially of aluminum and incidental impurities.

5        21. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

about 17.0 weight percent silicon;

about 1.0 weight percent magnesium;

about 0.5 weight percent iron;

10        about 5.0 weight percent copper;

about 0.35 weight percent scandium;

about 0.01 to about 1.0 weight percent grain refiners; and

15        the remainder consisting essentially of aluminum and incidental impurities.

22. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

about 17.0 weight percent silicon;

about 1.0 weight percent magnesium;

20        about 1.5 weight percent iron;

about 0.6 weight percent copper;

about 0.5 weight percent nickel;

about 0.5 weight percent zinc;

about 0.3 weight percent tin;

25        about 0.35 weight percent scandium;

about 0.01 to about 1.0 weight percent grain refiners; and

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the remainder consisting essentially of aluminum and incidental impurities.

23. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

5           about 12.0 weight percent silicon;  
          about 0.6 weight percent magnesium;  
          about 1.3 weight percent iron;  
          about 3.5 weight percent copper;  
          about 0.4 weight percent manganese;  
10          about 0.5 weight percent nickel;  
          about 3.0 weight percent zinc;  
          about 0.35 weight percent tin;  
          about 0.35 weight percent scandium;  
          about 0.01 to about 1.0 weight percent grain  
15   refiners; and

the remainder consisting essentially of aluminum and incidental impurities.

24. An aluminum-based casting alloy, as claimed in claim 13, consisting essentially of:

20           about 12.0 weight percent silicon;  
          about 1.0 weight percent magnesium;  
          about 1.3 weight percent iron;  
          about 1.0 weight percent copper;  
          about 2.5 weight percent nickel;  
25          about 0.35 weight percent zinc;  
          about 0.35 weight percent scandium;  
          about 0.01 to about 1.0 weight percent grain  
refiners; and

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the remainder consisting essentially of aluminum and incidental impurities.

25. An aluminum-based casting alloy comprising:  
from about 3.0 to about 25.0 weight percent  
5 silicon;  
from about 0.01 to about 2.0 weight percent  
zirconium;  
from about 0.01 to about 10.0 weight percent  
scandium; and  
10 from about 60 to about 97 weight percent  
aluminum.

26. An aluminum-based casting alloy, as claimed in claim 25, wherein said alloy comprises from about 0.1 to about 2.0 weight percent scandium.

- 15 27. An aluminum-based casting alloy, as claimed in claim 26, wherein said alloy comprises from about 0.1 to about 0.7 weight percent scandium.

28. An aluminum-based casting alloy comprising:  
from about 3.0 to about 25.0 weight percent  
20 silicon;  
from about 0.01 to about 10.0 weight percent  
scandium;  
up to about 1.0 copper; and  
from about 60 to about 97 weight percent  
25 aluminum.

29. An aluminum-based casting alloy, as claimed in claim 28, wherein said alloy comprises from about 0.1 to about 0.7 weight percent scandium.

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30. An aluminum-based casting alloy, as claimed in claim 29, wherein said alloy comprises from about 0.1 to about 0.5 weight percent scandium.

31. An aluminum-based casting alloy, as claimed in claim 28, consisting essentially of:

from about 3.0 to about 25.0 weight percent silicon;

from about 0.01 to about 10.0 weight percent scandium;

up to about 1.0 weight percent copper;

up to about 3.0 weight percent nickel;

up to about 0.1 weight percent magnesium;

up to about 0.5 weight percent manganese;

up to about 3.0 weight percent iron;

up to about 0.5 weight percent chromium;

up to about 1.0 weight percent zinc;

up to about 0.2 weight percent tin;

up to about 2.0 weight percent grain refiners;

up to about 0.1 weight percent chemical modifiers;

up to about 0.3 weight percent phase refiners;

and

the remainder consisting essentially of aluminum and incidental impurities.

32. An aluminum-based casting alloy, as claimed in claim 28, consisting essentially of:

about 12.0 weight percent silicon;

about 2.0 weight percent iron;

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about 1.0 weight percent copper;  
about 0.35 weight percent manganese;  
about 0.5 weight percent nickel;  
about 0.5 weight percent zinc;  
5 about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and

the remainder consisting essentially of aluminum  
and incidental impurities.

10 33. An aluminum-based casting alloy, as claimed in  
claim 28, consisting essentially of:

about 6.0 weight percent silicon;  
about 0.6 weight percent iron;  
about 0.25 weight percent copper;  
15 about 0.35 weight percent manganese;  
about 0.5 weight percent zinc;  
about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and

20 the remainder consisting essentially of aluminum  
and incidental impurities.

34. An aluminum-based casting alloy comprising:  
from about 2.0 to about 12.0 weight percent zinc;  
from about 0.01 to about 3.0 weight percent  
25 magnesium;  
from about 0.01 to about 10.0 weight percent  
scandium;

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from about 60 to about 98 weight percent aluminum, wherein said alloy is substantially free of chromium.

35. An aluminum-based casting alloy, as claimed in  
5 claim 34, wherein said alloy comprises from about 0.1 to about 0.7 weight percent scandium.

36. An aluminum-based casting alloy, as claimed in claim 35, wherein said alloy comprises from about 0.1 to about 0.5 weight percent scandium.

10 37. An aluminum-based casting alloy, as claimed in claim 34, consisting essentially of:

from about 2.0 to about 12.0 weight percent zinc;  
from about 0.01 to about 3.0 weight percent  
magnesium;

15 from about 0.01 to about 10.0 weight percent  
scandium;

up to about 0.5 weight percent silicon;  
up to about 2.0 weight percent copper;  
up to about 0.2 weight percent nickel;  
20 up to about 1.0 weight percent manganese;  
up to about 2.0 weight percent iron;  
up to about 0.2 weight percent tin;  
up to about 2.0 weight percent grain refiners;  
up to about 0.1 weight percent chemical  
25 modifiers;

up to about 0.3 weight percent phase refiners;

and

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the remainder consisting essentially of aluminum and incidental impurities.

38. An aluminum-based casting alloy, as claimed in claim 34, consisting essentially of:

5           about 7.0 weight percent zinc;  
          about 1.5 weight percent magnesium;  
          about 0.35 weight percent scandium;  
          about 0.01 to about 1.0 weight percent grain  
refiners; and

10           the remainder consisting essentially of aluminum  
and incidental impurities.

39. An aluminum-based casting alloy comprising:

          from about 2.0 to about 10.0 weight percent tin;  
          from about 0.01 to about 10.0 weight percent  
15 scandium;  
          from about 60 to about 98 weight percent  
aluminum.

40. An aluminum-based casting alloy, as claimed in claim 39, wherein said alloy comprises from about 0.1 to  
20 about 0.7 weight percent scandium.

41. An aluminum-based casting alloy, as claimed in claim 40, wherein said alloy comprises from about 0.1 to about 0.5 weight percent scandium.

42. An aluminum-based casting alloy, as claimed in  
25 claim 39, consisting essentially of:

          from about 2.0 to about 10.0 weight percent tin;  
          from about 0.01 to about 10.0 weight percent  
scandium;

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up to about 1.0 weight percent magnesium;  
up to about 10.0 weight percent silicon;  
up to about 5.0 weight percent copper;  
up to about 2.0 weight percent nickel;  
5 up to about 0.5 weight percent manganese;  
up to about 1.0 weight percent iron;  
up to about 2.0 weight percent grain refiners;  
up to about 0.1 weight percent chemical  
modifiers;  
10 up to about 0.3 weight percent phase refiners;  
and

the remainder consisting essentially of aluminum  
and incidental impurities.

43. An aluminum-based casting alloy, as claimed in  
15 claim 39, consisting essentially of:

about 6.0 weight percent tin;  
about 0.7 weight percent silicon;  
about 1.0 weight percent copper;  
about 1.0 weight percent nickel;  
20 about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and

the remainder consisting essentially of aluminum  
and incidental impurities.

25 44. An aluminum-based casting alloy, as claimed in  
claim 39, consisting essentially of:

about 6.0 weight percent tin;  
about 2.5 weight percent silicon;

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about 1.0 weight percent copper;  
about 0.5 weight percent nickel;  
about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
5 refiners; and  
the remainder consisting essentially of aluminum  
and incidental impurities.

45. An aluminum-based casting alloy, as claimed in  
claim 39, consisting essentially of:  
10 about 6.0 weight percent tin;  
about 0.4 weight percent silicon;  
about 0.7 weight percent magnesium;  
about 2.0 weight percent copper;  
about 1.2 weight percent nickel;  
15 about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and  
the remainder consisting essentially of aluminum  
and incidental impurities.

20 46. An aluminum-based casting alloy, as claimed in  
claim 39, consisting essentially of:  
about 6.0 weight percent tin;  
about 6.0 weight percent silicon;  
about 3.5 weight percent copper;  
25 about 0.35 weight percent scandium;  
about 0.01 to about 1.0 weight percent grain  
refiners; and

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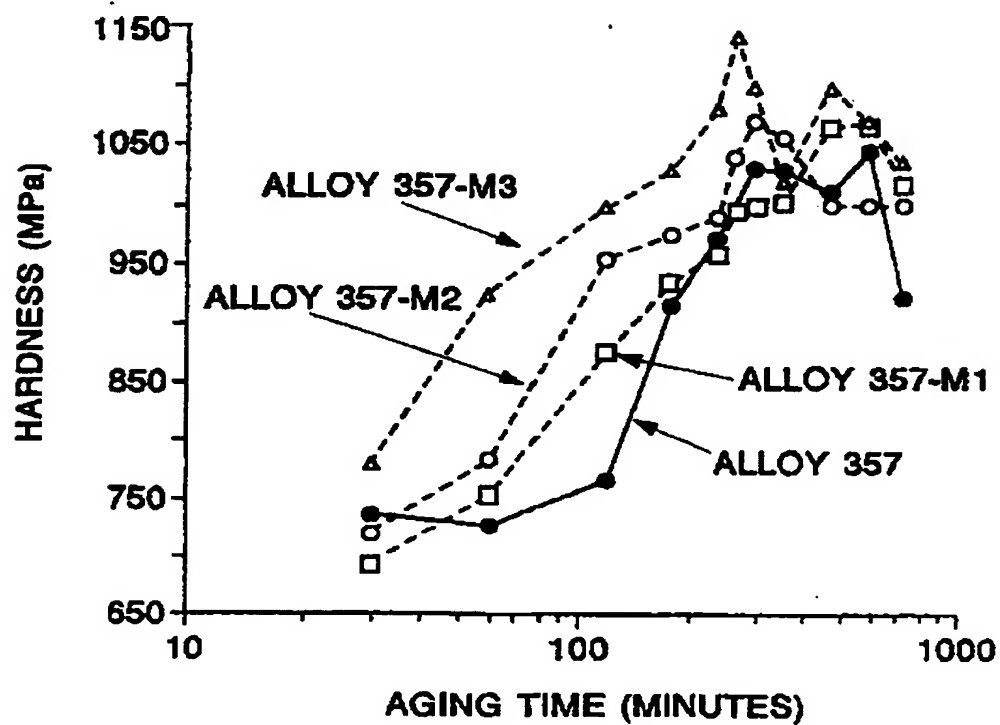
PCT/IB95/01022

-48-

the remainder consisting essentially of aluminum  
and incidental impurities.

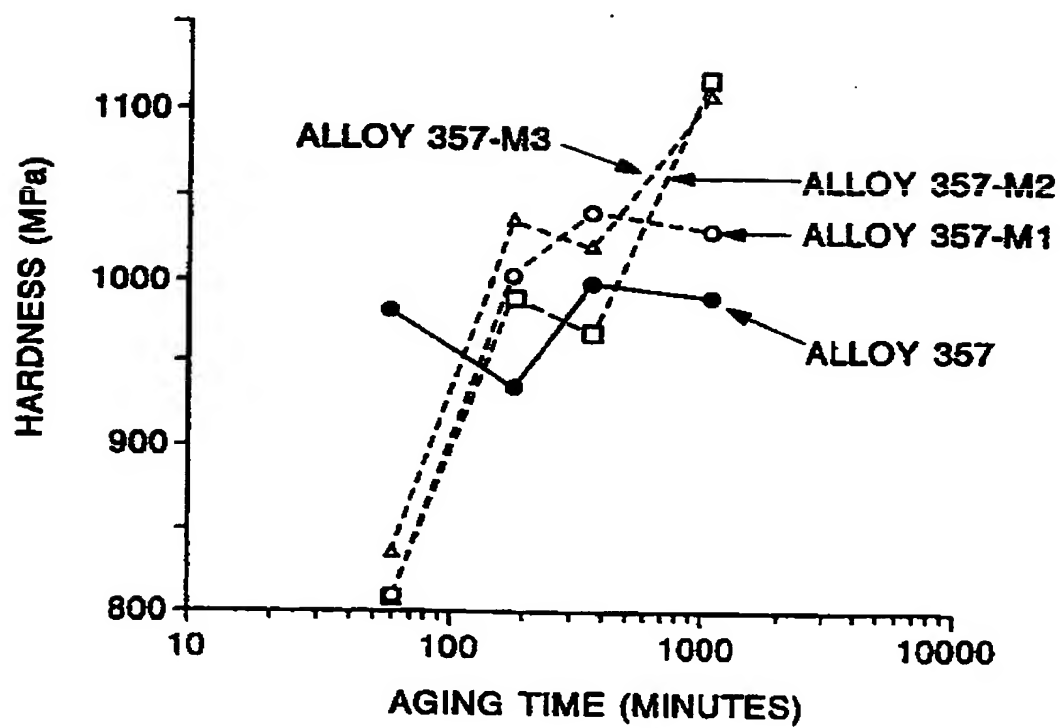
1/3

FIGURE 1:



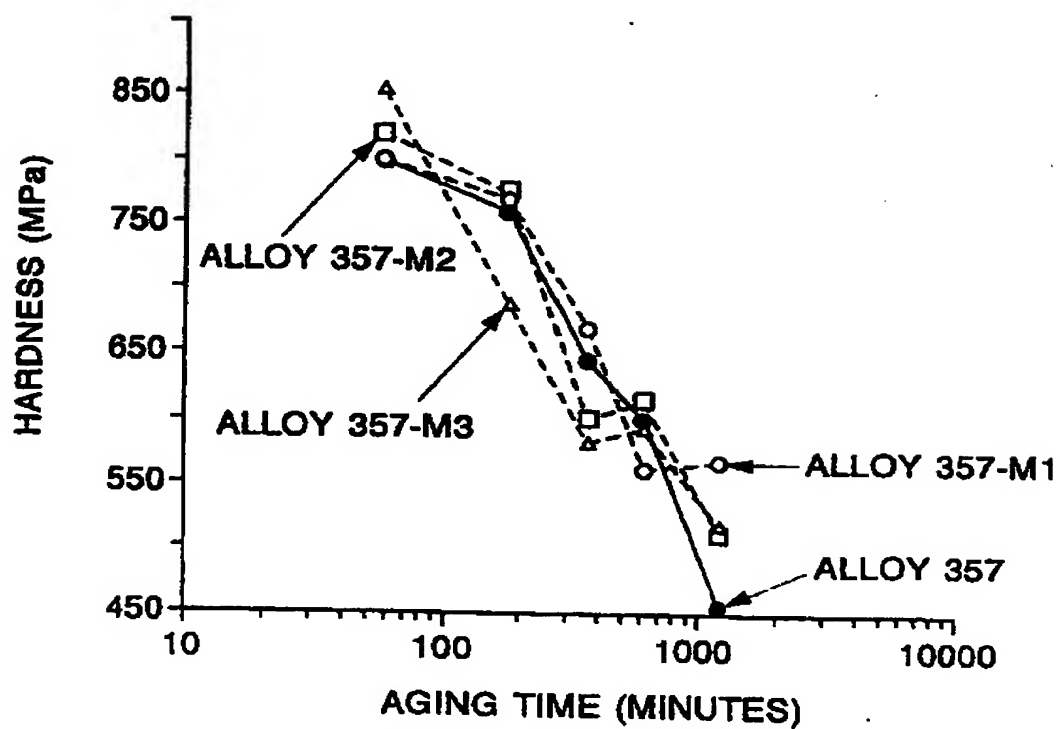
2/3

FIGURE 2:



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FIGURE 3:



## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/IB 95/01022

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 C22C21/02 C22C21/16 C22C21/00 C22C21/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ACTA METALLURGICA AND MATERIALIA, vol. 42, no. 7, July 1994 EXETER, GB, pages 2285-2290, XP 000563099 M.L.KHARAKTEROVA ET AL 'PRECIPITATION HARDENING IN TERNARY ALLOYS OF THE AL-SC-CU AND AL-SC-SI SYSTEMS' see page 2286, column 1, paragraph 2; figures 1,3; table 1 ---	1-33
A	DATABASE WPI Section Ch, Week 9407 Derwent Publications Ltd., London, GB; Class M26, AN 94-055059 & RU.C.2 001 150 ( TRIUMF RES PRODN ASSOC) , 15 October 1993 see abstract --- -/--	1,7,12, 13,25, 28,34,39

☒ Further documents are listed in the continuation of box C.

☐ Patent family members are listed in annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

27 February 1996

Date of mailing of the international search report

08.03.96

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/IB 95/01022

C.(Continuation), DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>DATABASE WPI Section Ch, Week 9407 Derwent Publications Ltd., London, GB; Class M26, AN 94-055053 &amp; RU,C,2 001 144 ( MOSC STEEL ALLOYS INST) , 15 October 1993 see abstract</p> <p style="text-align: center;">---</p>	<p>1,7,12, 13,25, 28,34,39</p>
A	<p>DATABASE WPI Section Ch, Week 7714 Derwent Publications Ltd., London, GB; Class M26, AN 77-24450Y &amp; JP,A,52 024 908 ( SHOWA DENKO KK) , 24 February 1977 see abstract</p> <p style="text-align: center;">---</p>	<p>1,7,12, 13,25, 28,34,39</p>
A	<p>DATABASE WPI Section Ch, Week 9518 Derwent Publications Ltd., London, GB; Class M26, AN 95-137536 &amp; SU,A,1 767 915 ( AVIAT MATERIALS RES PRODN ASSOC) , 30 July 1994 see abstract</p> <p style="text-align: center;">---</p>	<p>1,7,12, 13,25, 28,34,39</p>
A	<p>DATABASE WPI Section Ch, Week 9407 Derwent Publications Ltd., London, GB; Class M26, AN 94-055054 &amp; RU,C,2 001 145 ( MOSC STEEL ALLOYS INST) , 15 October 1993 see abstract</p> <p style="text-align: center;">---</p>	<p>1,7,12, 13,25, 28,34,39</p>
A	<p style="text-align: center;">---</p> <p>CHEMICAL ABSTRACTS, vol. 116, no. 8, 24 February 1992 Columbus, Ohio, US; abstract no. 64940. ROYANOV, A. A. ET AL 'Aluminum-magnesium-silicon alloy' see abstract &amp; SU,A,1 657 538 (BAIKOV, A. A., INSTITUTE OF METALLURGY, USSR)</p> <p style="text-align: center;">---</p>	
A	<p style="text-align: center;">---</p> <p>CHEMICAL ABSTRACTS, vol. 101, no. 10, 3 September 1984 Columbus, Ohio, US; abstract no. 77359, DRITS, M. E. ET AL 'Effect of homogenizing heating on the properties of aluminum-scandium and aluminum-magnesium-scandium alloys' see abstract &amp; IZV. AKAD. NAUK SSSR, MET. (1984), (3), 198-201 CODEN: IZNMAQ;ISSN: 0568-5303, 1984</p> <p style="text-align: center;">---</p> <p style="text-align: center;">-/--</p>	

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/IB 95/01022

## C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>JOURNAL OF MATERIALS SCIENCE, vol. 20, 1985 LONDON GB, pages 2861-2867, N.BLAKE ET AL 'CONSTITUTION AND AGE HARDENING OF AL-SC ALLOYS' -----</p>	